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Case Studies in Run-to-Run Control and Fault Detection for Flat Panel Display Manufacturing

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Purpose: This paper highlights case studies for run-to-run (R2R) control and fault detection (FD) in the flat panel display (FPD) industry using Applied E3™, focusing on the benefits achieved through application of these technologies. Comparisons to design and implementation in the semiconductor industry are provided to highlight the key similarities and differences between the industries.

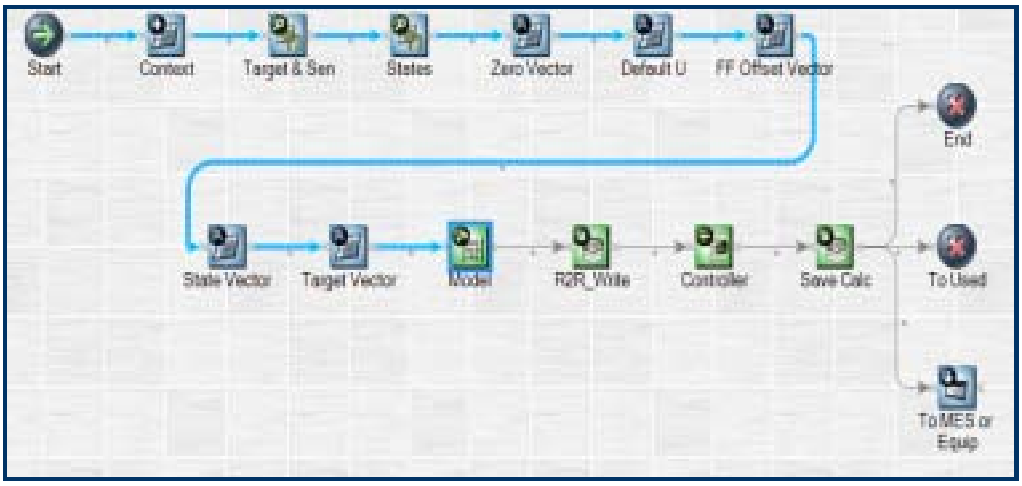
Description of Approach: Advanced process control (APC) methodologies that are commonplace within semiconductor manufacturing are now migrating to other key technology areas, such as flat panel display. In the case of R2R and FD control, many of the traditional semiconductor event logic flows, or "strategies" can be transferred directly to FPD manufacturing, while others require modification; in some cases, FPD manufacturing requires design of strategies that address its unique processes. This paper highlights the design, construction, and testing methodologies used during the evaluation of the R2R and FD control solutions in FPD manufacturing.

The flat panel display industry has several similarities and differences compared with the semiconductor industry that presents unique control and fault detection challenges. (1) Substrate, equipment, and device size: FPD glass is approximately 100X the area of a semiconductor wafer with corresponding changes to equipment size and control systems. (2) Product and technology mix: FPD lines run multiple products and technologies simultaneously and the R2R controller performance is impacted by design decisions such as context used for parameter updates. (3) Frequency of metrology operations: Within FPD, metrology operations are relatively infrequent, posing inherent challenges to the R2R controller design.

This presentation provides two case studies in the FPD industry: development of an R2R controller for photolithography, and FD in the deposition process chamber. For each case, a general problem solving methodology was used that included, 1) a discovery process to understand the problem statement, 2) defining a data collection plan and collecting several runs of data, 3) performing a run-to-run or fault detection analysis by comparing production data from good and bad runs, and 4) reviewing benefits and return on investment with data collected from the manufacturing process.

Evaluation of Results: An R2R controller was designed to increase the process capability for overlay and exposure control module. Details of the controller and strategy design, along with configuration information (context, model, configuration tables) are provided. Simulation data were used to design and validate the controller, and estimated controller performance relative to current plan of record results is provided. In general, the main benefit for control is centering the target distribution and reduction of variability to provide process capability improvement and reduction of out-of-specification material. The controller development has led to a reusable methodology for design of control systems within the Applied E3 APC software framework. Figure 1 shows the strategy design and model structure for these controllers. Reuse of design and common controller methodology simplifies support and maintenance. Savings due to throughput improvements alone for this controller are estimated to be $36k/month, as shown in Table 1.

Equipment FD was implemented on the deposition process chamber to reduce the scrap rate caused by vacuum leaks. A vacuum leak triggers a fault condition. Selection of sensors (e.g., pressure and RF power) for the FD model is similar to the semiconductor equipment counterpart. This FD case study highlights the unique challenges in implementation in the FPD industry and the capabilities achieved by applying FD models. A portion of the fault detection strategy is shown in Figure 2. A benefit analysis was performed to determine the impact of the expected number of faults/tool/month, and fault events were observed in production. In leak detection, the return on investment can be measured in months depending on assumptions of impacted substrates and leak frequency, as shown in Table 1.



$$\begin{bmatrix} x_{1,k+1} \\ x_{2,k+1} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_{1,k} \\ x_{2,k} \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} [u_k], \qquad \begin{bmatrix} x_{1,0} \\ x_{2,0} \end{bmatrix} = \begin{bmatrix} 0 \\ d_0 \end{bmatrix}$$

$$y_k = [b \quad 1] \begin{bmatrix} x_{1,k} \\ x_{2,k} \end{bmatrix}$$

Figure 1: R2R strategy in Applied E3 with the corresponding state-space model formulation.

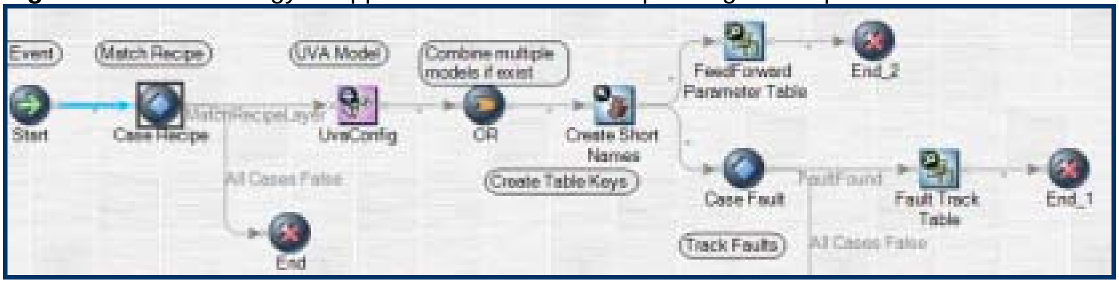


Figure 2: A portion of the fault detection strategy in the Applied E3 APC workflow solution.

Table 1: Savings estimates for R2R and FD case studies

Process	Overlay and CD control
APC type	R2R control
Anticipated Cpk improvement	> 30 %
Additional benefits	Reduce rework/out-of-spec material
Savings	$36K/month
Process	Leak detection
APC type	Fault detection
Anticipated number of leaks	1/month
Time to nominal detection	6 hrs
Manufacturing throughput	30K panels/month
Panel value	$3,000 per unit
Raw glass cost	$1,500 per unit
Savings from scrap reduction	> $350K/month